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Citation style: Zuberek Wacław M., Teper Lesław, Idziak Adam F., Sagan Grzegorz. (1996). Tectonophysical approach to the description of mining induced seismicity in the Upper Silesia. W: A. Idziak (ed.), "Tectonophysics of mining areas" (S. 79-98). Katowice: Uniwersytet Śląski.

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Tectonophysical Approach to the Description of Mining Induced Seismicity in the Upper Silesia

Abstract

Seismicity occurring in the Upper Silesian Coal Basin (the USCB) is induced by deep underground coal mining and is relatively well recorded and recognized. The majority of tremors occurring there, is closely related to mining so only mining induced stresses were considered to be the cause of the tremors. The frequency energy distribution of mine tremors in the USCB has indicated the evident bimodal features: the lower energy mode, closely related to mining and the largest energy indicating the relation to the geological structures of the USCB. Therefore the research has been undertaken to explain if there is any tectonic influence on mine tremors occurrence and to formulate a seismotectonic model of state of deformation and stresses in the rock mass of the USCB responsible together with mining activity for the mine tremors generation.

The obtained results indicate that tectonics plays a significant role in the occurrence of at least some of the largest mining tremors in the USCB area and the tectonophysical analysis can explain some relations in their occurrence. On the basis of seismotectonic model constructed for the USCB area we can conclude that the parameters of strain ellipsoid as well as of the seismic moment tensor and regional stress tensor for some mine tremors are almost the same. Some parts of the Upper Silesian Coal Basin (e.g. the zones of large latitudinal faults) are related to the large discontinuities in the deep crustal basement with active shear stresses. The equilibrium disturbance due to the reduction of vertical stress component caused by mining, erosion of the Carpathian overlap or the postglacial rebound may result in unstable behaviour in these zones and one can expect recent horizontal and vertical movements there.

We also underline that the application of the optimum method of direct stress (strain) measurement it the rock mass for conditions of the USCB is necessary as well as that the modernization of seismological networks existing there is inevitable.

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Introduction

Mining induced seismicity is occurring in Poland in the areas of extensive underground and surface mining. The Upper Silesian Coal Basin (USCB) is an area where the very intense examples of the dynamic events have been observed on the surface and in underground workings in numerous coal mines operating there. The tremors occurring there are closely related to coal bumps often observed underground which were causing one of the very important hazard and therefore have been the subject of extensive research since several years.

Since the last time the evidence has been increasing all over the world that mining induced seismicity is strongly affected by local geology, especially tectonics and is a result of mutual interaction between mining, lithostatic and tectonic stresses at local and regional scales (Gibowicz, 1990a, b; Gibowicz, Kijko, 1994; McGarr et al., 1989; Idziak et al., 1991; Teper et al., 1992; Sagan, Zuberek, 1995; Zuberek et al., 1997). There is no doubt, that the majority of tremors, especially those in the lower seismic energy range, is closely related to mining activity so it seems that only mining induced stresses appear to be their cause, and not any tectonic influence. Some of the largest tremors occurring in the USCB however, have regional features and can not be well explained by mining activity only.

The development of seismology has created the opportunity to estimate the source mechanism of well recorded tremors and to determine the orientation of their fault planes, type of failure and further, under some assumptions, the direction of acting forces responsible for their generation and relative ratio of the main stress tensor components. On the other hand, the detailed structural and tectonic analysis of deformation pattern of the rock mass enables the reconstruction of the strain ellipsoid, and the identification and recognition of main causes responsible for their generation.

So it seems that the time is coming to introduce to mining engineering the modern complex methods of the seismological, geomechanical, structural and tectonic data analysis which we propose to call mining tectonophysics modifying and enlarging the former definitions (Kidybiński, 1982; Goszcz, 1986). By the analogy to the geophysical definition of tectonophysics, we propose to understand under this term the methods and techniques permitting to relate the dynamic processes occurring in the rock mass and the results of deformation observations to their origins which are usually not accessible to direct observations. Therefore, in regard to the mining tectonophysics would be discipline of geophysical science dealing with forces and stresses inducing movements and deformations of the rock mass subjected to exploitation. It has been encompass at diverse range of research activity with strong interdisciplinary ties to rock mechanics, structural geology, mining tectonics and mining seismology.

In the paper we are trying to present such type of analysis basing on results of the research undertaken to explain if there is any tectonic influence on mine tremors occurrence in the USCB with an attempt to formulate a seismotectonic model of state of deformation in the rock mass responsible together with mining activity for the mine tremor generation.

The research has been supported by funds from governmental project KBN no. 9S60204503.

Seismicity of the USCB

The induced seismicity of the USCB is relatively well recorded by several seismological networks operating there. Recently there are about 800 tremors with seismic energy larger than 10^5 J ($M_L \geq 1.7$) and about 100 events with seismic energy larger than 10^6 J ($M_L \geq 2.3$) recorded every year.

The sources of tremors in the USCB are not distributed uniformly over the area of the coal basin but are clustering in some regions. Approximately 85% of all events occur in two regions namely the Bytom syncline and the Main anticline (Fig. 1). In these areas also the largest tremors occur e.g. tremor from coal mine Śląsk ($E = 8\times10^9$J, $M_L = 4.3$) in 1985 and tremor from coal mine Szombierki ($E = 2\times10^{10}$J, $M_L = 4.5$) in 1980. The other regions of mine tremors occurrence are:

- Kazimierz syncline with decaying seismic activity and tremors in the lower seismic energy range ($E < 1 \times 10^8$ J, $M_L < 3.3$),
- Jejkowice syncline,
- Jastrzębie region (anticline and syncline),
- Main syncline is relatively new region of mining induced seismicity with slowly increasing activity. The largest tremor was observed there in May 1992 with seismic energy 2×10^9J ($M_L = 4.0$) with the source distant approx. 1km from the nearest mining opening.

The majority of tremors felt on the surface do not cause any damage to existing buildings. Only the tremors with seismic energy $E \geq 1\times10^7$J ($M_L \geq 2.7$) which occur around 10 times a year can be destructive. For example, the largest one, which occurred at Szombierki coal mine (Sept. 30, 1980) has damaged 427 buildings in the town of Bytom (Knothe, 1991; Drzęźla, Zuberek, 1995).

Due to significant reduction of coal output in the last years a slow but distinct decrease of seismic activity with corresponding reduction of released seismic energy are observed.

There are at least two types of mine tremors with different features (Gibowicz, Kijko, 1994). The frequency-energy distribution of mine tremors in the USCB has indicated evident bimodal features and one can distinguish two different modes

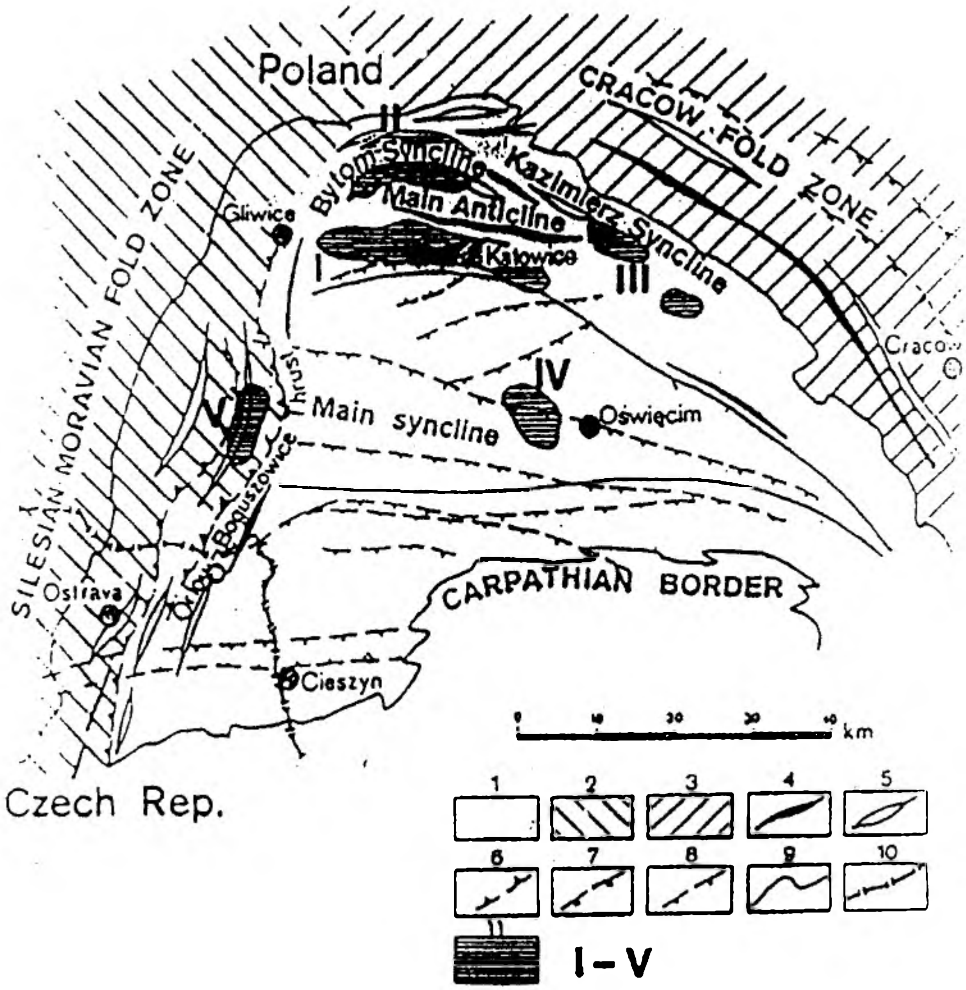


Fig. 1. Areas of mine tremors occurrence on the background of tectonic sketch of the USCB:
1 – zone of block tectonics; 2 – zone of fold tectonics; 3 – zone of fold-block tectonics; 4 – anticlines; 5 – synclines; 6 – thrusts; 7 – main faults; 8 – main faults of Alpine age; 9 – border of the USCB; 10 – Polish state border; 11 – seismic areas; I – the Main anticline; II – the Bytom syncline; III – the Kazimierz syncline; IV – the Main syncline; V – the Jejkowice syncline

of tremors (Marcak, 1985, Zuberek, 1986; Kijko et al., 1987; Idziak et al., 1991a). The first mode of mine tremors, observed mainly in the lower energy range, and therefore the most frequent one, is occurring near the operating openings. Their sources are closely related to face advances and are shifting respectively to their movements. The frequency-energy distributions obtained for that mode of tremors show similar features in different structural units of the USCB (Idziak et al., 1991a).

The second mode of mine tremors creates the largest energy events, much less frequent, with sources usually located far from active openings and therefore not directly related to mining, but related very often to existing fault zones. The type of the extreme value asymptotic distribution used for the description of the second mode looks different in selected structural units of the USCB (Idziak et al., 1991a) that may indicate some relation to the geological structure of the USCB.

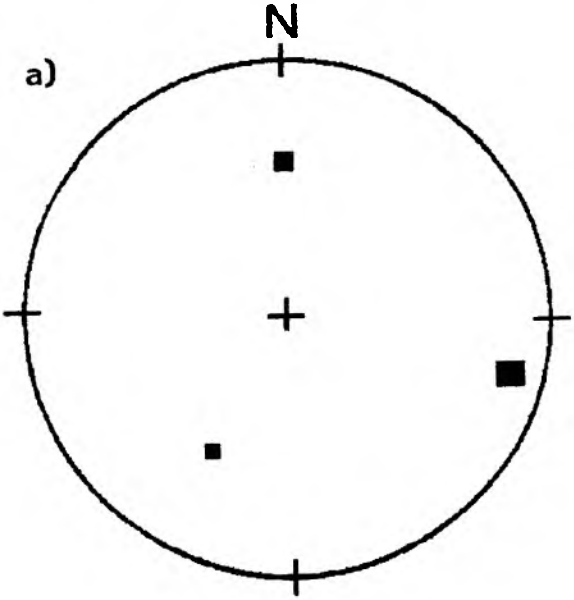
The analysis of the frequency-magnitude Gutenberg–Richter distribution of mine tremors from the Upper Silesia indicates that the coefficient b is usually in the range of $0.6<b<1.2$ for different regions that is in good agreement with other mining basins over the world (Dubiński, Syrek, 1990; Idziak, Zuberek, 1995). However we have found that b value is increasing with the increase of magnitude threshold and it obtains very large values in some time intervals. It may be derived that the Gutenberg-Richter distribution results from fractal distribution of seismic energy of mine tremors (Aki, 1981; Gibowicz, Kijko, 1994) with fractal dimension $D = 2b$. Therefore the deviation from Gutenberg–Richter distribution may be related to the deviation from the fractal distribution of tremor energy.

The spatial distribution of tremor epicentres has fractal features in the relatively wide range of scales and the fractal dimension D is different in selected geological structures of the USCB (Idziak, Zuberek, 1995), higher in the Bytom syncline ($D = 1.5$) and lower in the Main anticline ($D = 1.2$).

On the other hand the fractal analysis of the fault systems in the USCB (Teper, Idziak, 1995) delivered the conclusions that the whole fault structure of the USCB area is fractal with fractal dimension close to 2.0 indicating the evidence of the polyphase character of the whole fault network, while the selected fault systems, treated separately, have D-value close to 1.58 what may seem to point that each of them has been created due to one act of nature with minimum energy conditions (Hirata, 1989). For the Bytom syncline the fractal dimension obtained for space distribution of seismic sources is very close to that one obtained for fault system there.

Focal Mechanisms of Mine Tremors in the USCB

Focal mechanism investigations of mine tremors were carried out for the USCB region in the years 1990–1991 using the polarization of first arrivals and assuming shear failure mechanism in the source (Teper et al., 1992; Sagan, 1994; Sagan, Zuberek, 1995). On the basis of the spatial radiation pattern and polarization of the P waves emitted from the source two perpendicular nodal planes were estimated (fault plane solution) one of them being the fault plane during the tremor. The two biggest seismic areas of the USCB were chosen for this research: the Main anticline and the Bytom syncline. Both single and group fault plane solution methods were chosen for the determination of the nodal planes spatial orientation obtaining similar results which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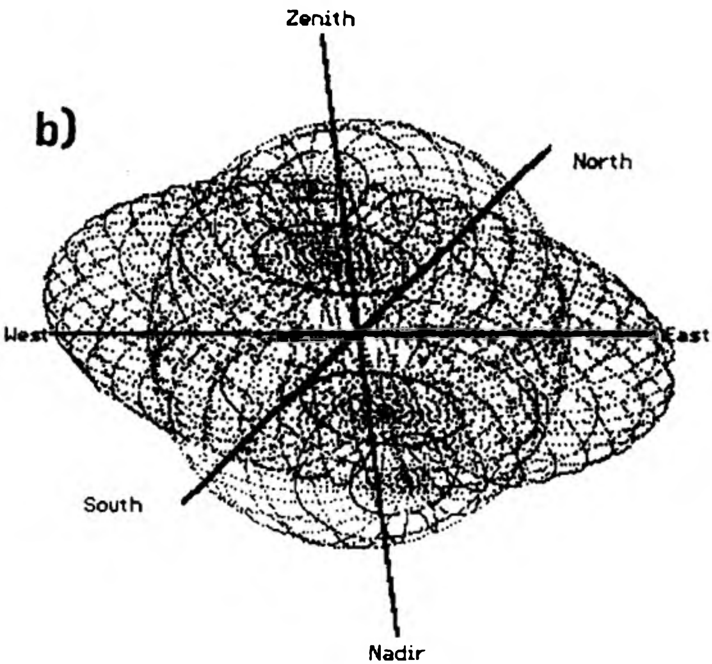
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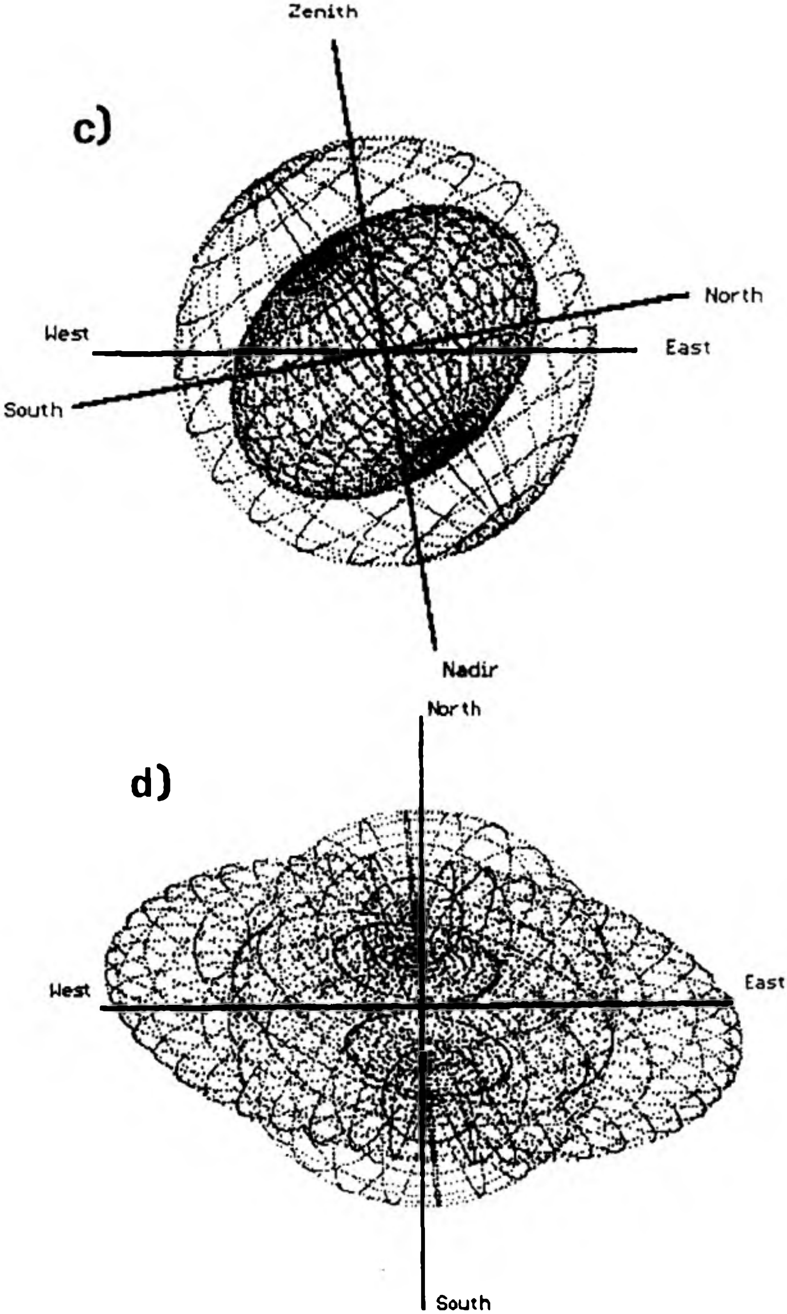


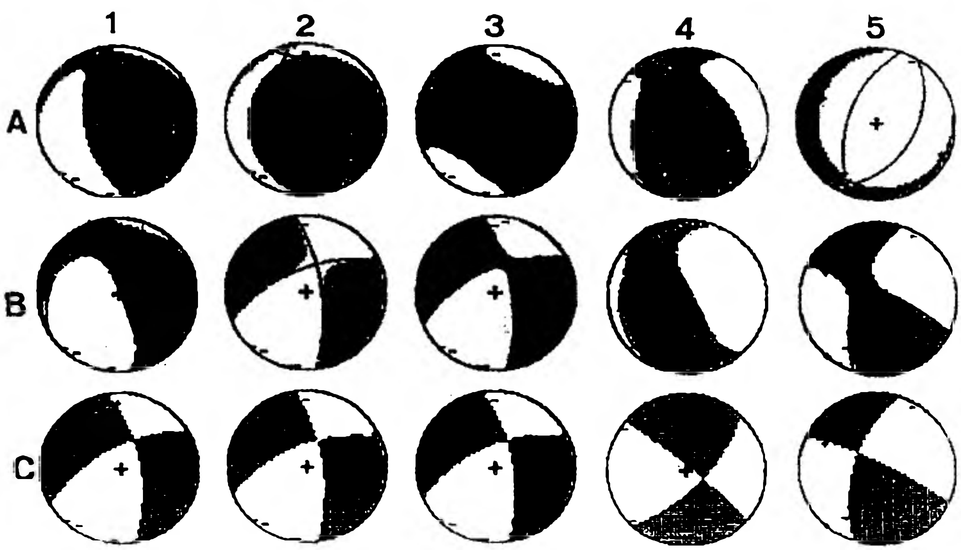
Fig. 2. Results of stress tensor analysis for the tremors with strike-slip fault mechanism:
a) computed tensor components in the equal area Schmidt upper hemisphere projection (the largest intermediate and smallest squares correspond to maximum, intermediate and minimum stress); b), c) and d) 3D axonometric projection of the stress ellipsoid for the above presented state of stress (the reference sphere indicates the compression and tension zones)

have confirmed the method. Analysing the obtained results for selected geological structures the differences between these two seismic regions have been observed.

The main type of focal mechanism in the Bytom syncline was the normal faulting with vertically (or very close to) oriented maximum stress (σ_1) axis. The strike azimuths of the nodal planes were not directly related to the regional tectonic lineaments (Sagan, 1994) and probably were related to the directions of underground mining there.

The mine tremors from the Main anticline area were much more diversified. For the focal mechanisms classified as normal faults the spatial orientation of σ_1 (maximum stress) axis was more scattered around the vertical axis than in the Bytom syncline area. About 15% of events were not classified as normal fault mechanisms e.g. strike-slip or reverse fault mechanisms. For strike-slip mechanisms, compression axis (σ_1) is dipping at angle less than 20° while the strike azimuths of nodal planes are rather consistent and concordant with NE-SW or NW-SE fault systems widely represented in the Upper Silesia.

One can compute the directions of the main stress tensor components (so called regional stress tensor) and the shape of the stress ellipsoid (Angelier, 1979) assuming that for different mine tremors with similar focal mechanisms occurring in the specified area stress tensor differs not so much and then the mean (regional) stress tensor exists (Yeh et al., 1991). The results of such calculations for the Main anticline area (coal mine Wujek) for tremors with strike-slip mechanism are presented in Fig. 2. (Sagan, Idziak, 1992). In Fig. 2a the computed stress tensor



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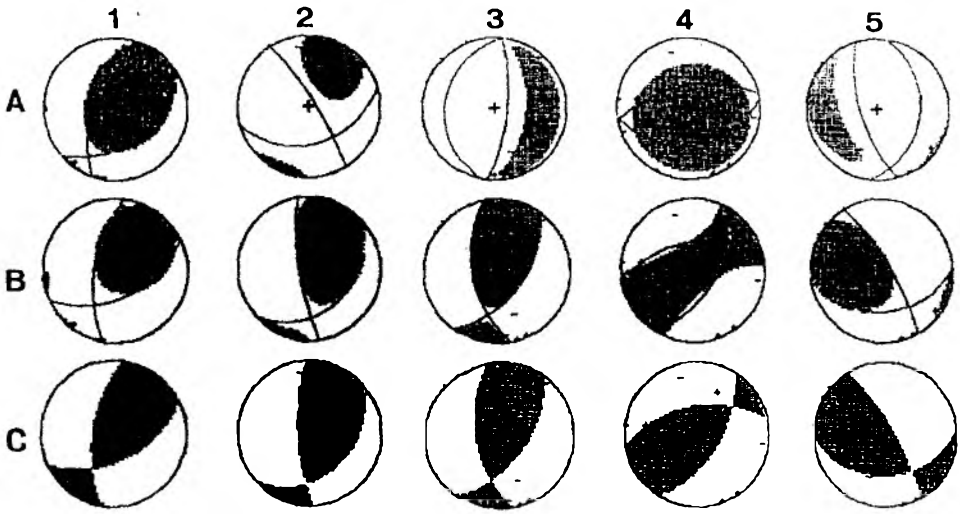

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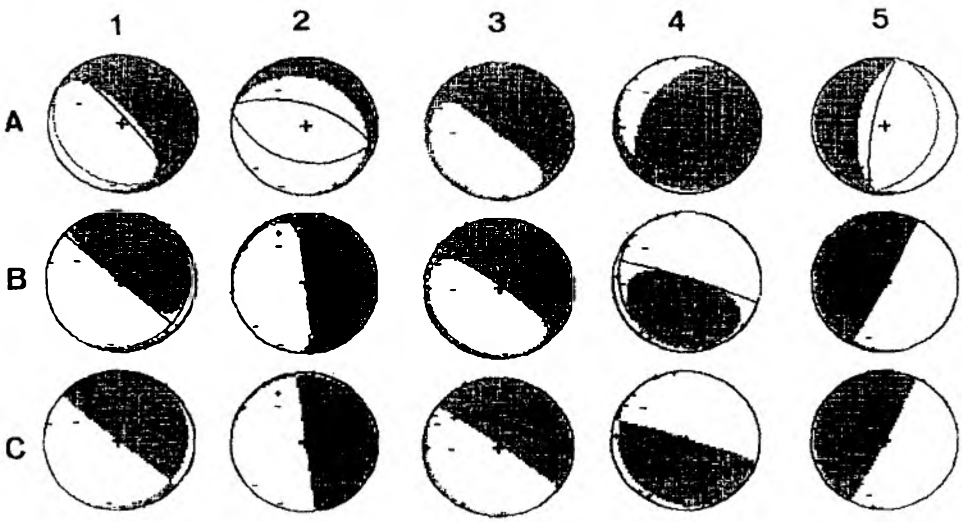

c)

Fig. 3. The seismic moment tensor solution for selected mine tremors from coal mines Wujek and Śląsk (lower hemisphere, Schmidt equal area projection, tremor parameters in Tab. 1):

a) tremors with the strike-slip DC component; b) tremors with the reverse dip slip DC component; c) tremors with the almost vertical fault plane (normal dip-slip) in a DC component; 1–5: number of event; A – full tensor; B – zero trace tensor; C – double-couple component

Table 1

Results of the seismic moment tensor solution for selected events from Wujek and Śląsk mines: a) events with strike-slip mechanism; b) events with the reverse fault mechanism; c) events with one vertical nodal plane (normal fault mechanism)

a)

No.	Date	Time h : min	Magnitude in M_L	Full Tensor [%]			Zero Trace [%]		Double Couple [degrees]				Mine	Norm
				(*) I	(*) CLVD	DC	(*) CLVD	DC	A-plane		B-plane			
									ϕ	δ	ϕ	δ		
1	6 Mar. 95	13:46	1.40	38.4	36.7	24.9	−10.2	89.8	351	60	241	59	Śląsk	L1
2	3 Mar. 95	18:47	1.16	47.8	48.8	3.3	9.7	90.3	353	67	247	58	Śląsk	L2
3	3 Mar. 95	18:47	1.16	42.3	15.4	42.3	−2.4	97.6	351	65	247	58	Śląsk	L1
4	30 Mar. 94	2:29	1.40	38.4	32.3	29.2	−11.0	89.0	310	83	44	63	Wujek	L1
5	19 Sep. 93	3:26	1.70	−19.1	−19.8	61.1	−10.1	89.9	294	78	197	58	Wujek	L2

b)

No.	Date	Time h : min	Magnitude in M_L	Full Tensor [%]			Zero Trace [%]		Double Couple [degrees]				Mine	Norm
				(*) I	(*) CLVD	DC	(*) CLVD	DC	A-plane		B-plane			
									ϕ	δ	ϕ	δ		
1	22 Mar. 95	10:47	1.08	25.4	32.5	42.1	45.9	54.1	187	60	64	47	Śląsk	L2
2	27 Dec. 94	23:21	1.16	−36.8	13.9	49.3	11.2	88.8	177	73	50	27	Śląsk	L1
3	9 Dec. 93	19:58	1.08	18.7	−18.4	62.9	1.8	98.2	171	51	38	50	Wujek	L2
4	4 Nov.	18:42	1.49	43.2	49.4	7.5	−19.4	80.4	33	53	261	48	Wujek	L2
5	19 Oct. 93	10:15	1.60	−19.7	−18.4	61.9	35.7	64.3	300	75	87	30	Wujek	L2

c)

No.	Date	Time h : min	Magnitude in M_L	Full Tensor [%]			Zero Trace [%]		Double Couple [degrees]				Mine	Norm
				(*) I	(*) CLVD	DC	(*) CLVD	DC	A-plane		B-plane			
									ϕ	δ	ϕ	δ		
1	16 Mar. 93	6:46	1.21	–10.8	–14.4	74.8	2.5	97.5	130	89	36	6	Wujek	L2
2	20 Mar. 93	4:51	1.19	–19.4	–19.7	60.9	–3.0	97.0	353	89	245	4	Wujek	L2
3	13 Dec. 93	10:42	1.03	10.2	5.7	84.1	–4.1	95.9	306	86	152	4	Wujek	L2
4	13 Dec. 93	16:23	1.24	46.3	45.7	8.0	13.1	86.9	287	85	151	7	Wujek	L2
5	20 Dec. 93	0:03	1.24	–17.3	17.6	65.1	0.1	99.9	27	88	171	3	Wujek	L2

*(–) sign denotes dilatation or tension

components are presented in the equal area Schmidt projection of the largest, intermediate and minimum stress. The Fig. 2b, c, d present $3D$ projections of stress ellipsoid in some conventional form. The stresses are presented in relation to the reference sphere with compression and tension stresses inside and outside of this sphere, respectively.

The largest stress component for these tremors is extensional and is oriented horizontally approx. in W-E direction. Both other stress components are compressional and are oriented diagonally. In that case it is difficult to explain the existing stress in the rock mass by mining stresses only and one can conclude that the tectonic horizontal stresses exist there.

Recently, calculations of seismic moment tensor has replaced fault plane solution of mine tremor mechanism (Sileny, 1989; McGarr, 1992; Wiejacz, 1991; Gibowicz, Kijko, 1994; Sagan, et al., 1996). In comparison to the former fault plane solution it gives the opportunity to consider other stress components than only the shear ones but it needs high quality seismic records, larger dynamic range of recording channels, digital recordings and good spatial coverage of the seismological network around the source, not always obtainable at operating networks at the coal mines.

In Poland the moment tensor calculations has been introduced to the analysis of the mechanisms of Upper Silesia tremors on the basis of the algorithm with amplitude inversion in the time domain and computer SMT program elaborated by P. Wiejacz (1994) from the Geophysical Institute of Polish Academy of Sciences. The SMT software calculates the total seismic moment tensor and decomposes it into the isotropic (I), the compensated linear vector dipole (CLVD) and the double couple (DC) components. The I component corresponds with the volumetric (extension – negative and compression – positive) stress components in the source. Both the CLVD and DC components form the deviatoric part of the moment tensor while DC component corresponds with the typical shear stress component at the source. The program also calculates the spatial orientation of two perpendicular nodal planes (A and B) and the orientation of pressure (P) and tension (T) axes. All calculations are done using both L1 and L2 norms (Gibowicz, Kijko, 1994) but usually there are not significant differences between results.

It has been found (Sagan et al., 1996; Sagan et al., 1995) that in majority of tremors and coal bumps the deviatoric component of the moment tensor is dominant, and generally for approx. 70% of mine tremors the DC component exceeds 60% of the total moment tensor. At present, the physics of tremors with large I or CLVD components is not quite clear and can result from errors in some basic assumptions (Gibowicz, 1992). The conclusion that large DC (shear) component in the mechanism of mine tremors is dominant is important because it supports the validity of results obtained earlier by fault plane solution although we have to accept that there may exist a small group of mine tremors with other than shear mechanism in the source.

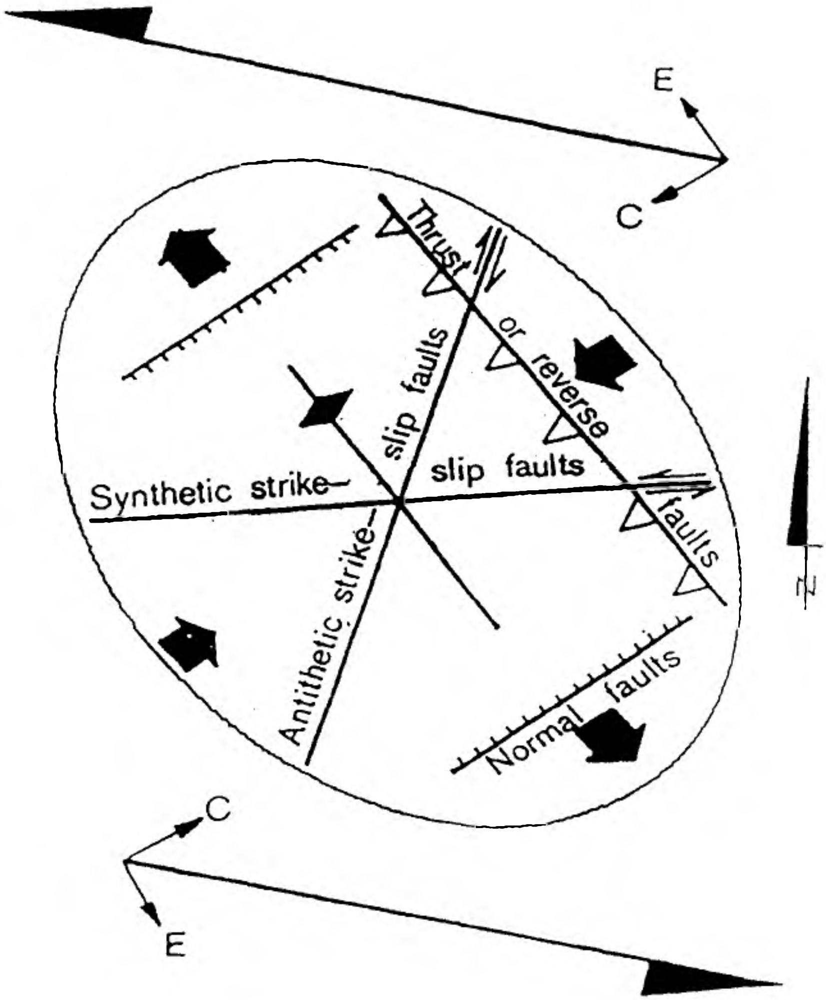

Fig. 4. Derivative pattern of neotectonic deformation of the USCB generated by force couple acting along the W-E directed fracture in crystalline basement (after Teper, Sagan, 1995)

The analysis of the nodal planes of the DC (shear) component of the moment tensor for the Main anticline region (coal mine Wujek) indicates that (Sagan et al., 1996):

- azimuths of strike of normal fault mechanisms (assuming that the vertical nodal plane is a fault plane) are concordant with major strikes of faults existing there (major direction N-S, minor NE-SW),
- some (limited number) events gave strike-slip mechanism at the source (Fig. 3a); it looks that those tremors are very interesting because they indicate

horizontal stress in the rock mass difficult to explain by mining only and probably indicating horizontal tectonic stresses existing there,
- solutions of some tremors suggest that displacement on NW-SE oriented reverse faults may also occur.

Several examples of moment tensor calculations for coal mines Wujek and Śląsk are presented on Fig. 3 and in Tab. 1.

The focal mechanisms of the presented events were calculated using 8-station network in Śląsk mine and 12-station network in Wujek mine. The tremors are divided according to the spatial orientation of the nodal planes of DC component. In majority of cases the good agreement of the zero trace and pure DC solutions can be observed, the solutions assuming only deviatoric components give the significant predominance of DC component and rather random CLVD component. The full tensor solutions confirm the general results from previous research (Sagan et al., 1996) when two main types of tremors were determined: the first one with dominant DC component and the second one with dominant I and CLVD components.

Summary of the Results From Structural Research

The research of tectonics based mainly on the field observations and mesostructural measurement and delivered following conclusions (Teper, 1988, 1990a, b, c; Cabała, Teper, 1990; Idziak et al., 1991b; Teper et al., 1992):

1. Main tectonic elements of the Carboniferous rock mass were created during the tectogenic phases following immediately coal bearing sedimentation and some of them are even syngenetic.

2. Great number of main disjunctive structures has the nature of secondary faults following the older tectonic directions and reflecting the kinematics of the USCB basement blocks movements.

3. The main structural features of the Alpine age observed in the rock mass are similar to the ones created before.

4. The first rank tectonic structure along NE border of the Upper Silesia Massif (the Cracow deep fault) is influencing the rock mass deformation in the USCB. The activity of this deep fault in the basement marked by the periodic successions of transtension and transpression created the system of fold and fault structures in the USCB area and its NE boundary. Regularity, geometry and type of system are typical for the strike-slip (wrench) stress field.

5. From the Tertiary the above mentioned strike-slip zone is oriented diagonally to the axis of the lithosphere plate rotation. The new dynamic state of the earth caused folding in the Carpathian arc. Its foreland was overlain by the Outer Carpathian thrust sheets. Ultimately the thrusting in Northern Carpathians became

locked during the Middle Miocene. The parameters of the strain tensor caused the W-E trending deep faults to be in a privileged position for their reactivation. The stress field responsible for creation of the new structure pattern is really typical for tangential acting force couple causing the sinistral, horizontal displacement of the basement along the W-E direction (Fig. 4).

An Attempt of the Seismotectonic Model Construction for the USCB

Analysing the present state of tectonic stress in the USCB one has to consider the effect of last glaciations, the Carpathian overlap and residual and recent Alpine horizontal stresses (Teper, Sagan, 1995). Assuming the changes of cap rock loading as the one of tectonic influence on seismicity in the USCB one can predict that only normal faults may be common (maximum compressive stress σ_1 being vertically oriented). The results of changes of that stress would be best seen after relatively slow loading and fast unloading which would cause isostatic uplift of the area and stronger stretching along the one of horizontal axes. The loading and unloading from the glacial cover took place during Mindel and Riss periods (Pleistocene). The loading started from the northern part of the coal basin so the northern part might have been most loaded because the thickness of glaciers decreases on the edge. The later unloading of the northern part would have been greater than the unloading of the southern part and uplift would cause the stretching along the N-S direction. Therefore one may expect the tectonic stresses and activity of normal faults with strikes concentrated along W-E direction. This effects ought to be more numerous in the northern part of USCB (the Bytom syncline, the Kazimierz syncline).

Neogene formation of the Carpathian overlap took place in the Miocene. The southern part of the USCB area was strongly loaded then and even the old W-E faults were reactivated. Their amplitudes reach more than 400 m. This loading had a similar effect to the glacial one but was greater and started from the south. Pliocene to recent erosion of the Carboniferous cap rock was one of the most important factors influencing the recent shape of the area. The USCB area was first subsided and next uplifted due to erosion at least to the first Quaternary glacial period (Teper, Sagan, 1995). In that regime normal W-E oriented faults could again have been produced or reactivated.

The horizontal orientation of the tectonic maximum stress (σ_1) is the basic condition of strike-slip fault formation. During the last interval of the geological history of the USCB folding in the Carpathian arc was the most significant tectonic event. The maximum horizontal stress had then mainly N-S orientation. Assuming that N-S oriented horizontal stress still exists we can expect it should have the biggest value on the southern border of the coal basin decreasing to the north. Studies on recent dynamics of the Carpathian belt point at reorientation of stress tensor since Tertiary. The deformation in the Outer Carpathians rolled around the arc in a clockwise fashion with time; deformation was both initiated and terminated first in the Northern Carpathians, then later in the Eastern Carpathians (Sandulescu, 1988). Main thrust type movements are observed now in the East Carpathians and the tectonic transport has SW-NE direction (Royden, 1988). Strain ellipsoid deduced on this base is similar to that one defined for the USCB area. The parameters of the strain tensor determine the presence of W-E oriented strike-slip zones (Teper, Sagan, 1995) (see Fig. 4) and explain their regional localization in the hinterland of compressional tectonic area (Morley, 1993). The existence of such strike-slip zone, which is connected with the neotectonic activity of the Carpathians, forms an essential principle of the presented model of recent dynamics in the Upper Silesia (Teper, Sagan, 1995).

The tectonics of the USCB was initiated by large scale strike-slip and transpressive movements along the first rank deep-seated fault which comprises the NE margin of the USCB basement (Teper, 1988). A deep-rooted, W-E oriented fracture set has controlled the formation of new tectonic structures as well as the rejuvenation and modification of the old ones since the Tertiary. The present dynamics of the studied area is dominated by the force couple acting in the W-E direction and causing sinistral movements along the fault located just beneath the Main anticline (Teper et al., 1992). As a consequence of the primary wrench faulting in the basement a derivative structural pattern has appeared in sedimentary cover (Fig. 4). In this pattern the active structures: synthetic and antithetic oblique-slip faults, strike-slip faults as well as normal and reverse faults have their positions determined by stress tensor typical for left lateral wrench zone (Tchalenko, 1970). Secondary strike-slip faults, in particular synthetic ones, occur next to the deep-seated master fault (Tchalenko, 1970; Hill, Beeby, 1977) while dip-slip normal faults usually broaden the range of the wrench zone in the sedimentary cover (Tchalenko, 1970; McCoss, 1986).

The presence of wrench movements suggests that the neotectonic stress field exists and occasionally gets narrow range of preconditions required for the strike-slip faults. In temporary stress tensor the vertical component usually does not retain an intermediate value but becomes either greatest or the least principal stress which is a frequent state in the strike-slip fault systems (Jaroszewski, 1984). The latest deformation has overprinted the previous structural pattern which has been controlled by the relative motions of crystalline blocks since the Variscan times (Teper, 1988; Cabała, Teper, 1990). Thus, the relaxation of recent stresses could be partially performed using reactivated, older discontinuities for a dip-slip motion. The essential part of presented model is possible uplifting of the region as it could form the conditions for strike-slip faulting. The central part of the USCB seems to be the region where the occurrence of typical strike-slip events is possible from the geological point of view.

Mine tremors, conditioned by neotectonic forces, should have strike-slip focal mechanisms when they occur in the narrow zone in close vicinity to the primary deep seated fault whereas dip-slip mechanisms will be expected for the events noted at greater distance. This principle holds true in the examined area. Moreover, the tectonic transport direction and relative displacements recorded using the classic fault plane solution technique (Teper et al., 1992) and seismic moment tensor inversion (Sagan et al., in press) are consistent with those anticipated by the model. The presented model summarises the possible most recent tectonic influence on seismicity in the USCB area. Though the wrench zone existence accompanied by derivative network of secondary faults is proposed, nevertheless the changes of the vertical loading seem to be the most important long-drawn factor which could interact with the tectogenic activity, as well as generate dynamic events itself.

Conclusions

1. The obtained results indicate that tectonics plays a significant role in the occurrence of at least some of the largest mine tremors in the USCB area and the tectonophysical analysis can explain some relations in their occurrence. Therefore it seams reasonable to undertake detailed tectonophysical investigations in the Upper Silesian Coal Basin.

2. The parameters of the strain ellipsoid and structural pattern, as well as the seismic moment tensor and regional stress tensor estimated on the basis of classic fault plane solution for mine tremors are almost the same in examined regions of the USCB. This indicates the existence of relationship between the seismicity and tectonics in the Upper Silesia.

3. Some parts of the Upper Silesian Coal Basin (e.g. the zones of large latitudinal faults) are related to the large discontinuities in the deep crustal basement with active shear stresses. The equilibrium disturbance due to reduction of vertical stress component caused by mining, erosion of Carpathian overlap or postglacial rebound may result in unstable behaviour in these zones and one can expect recent horizontal and vertical movements there. The unstability of faults have to be considered in geological sense which is not quite the same as in mining meaning.

4. Two types of the technical improvement seem to be reasonable for the development of tectonophysical investigations in the Upper Silesian Coal Basin. The first one is the application of optimum method of direct stress (strain) measurement in rock mass for conditions of the USCB. The second one is the moderniza-

tion of the seismological networks existing there for the proper registration and reliable monitoring of mine tremors. The modernization should include the introduction of digital recordings of mine tremors with significant increase of the dynamic range of the seismic channels.

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